Metaheuristics for multiobjective optimisation: Cooperative approaches, uncertainty handling and application in logistics

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PHD THESIS

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Abstract This is a summary of the author's PhD thesis supervised by Laetitia Jourdan and El-Ghazali Talbi and defended on 8 December 2009 at the Université Lille 1. The thesis is written in French and is available from http://sites.google.com/site/arnaudliefooghe/. This work deals with the design, implementation and experimental analysis of metaheuristics for solving multiobjective optimisation problems, with a particular interest on hard and large combinatorial problems from the field of logistics. After focusing on a unified view of multiobjective metaheuristics, we propose new cooperative, adaptive and parallel approaches. The performance of these methods are experimented on a scheduling and a routing problem involving two or three objective functions. We finally discuss how to adapt such metaheuristics during the search process in order to handle uncertainty that may occur from many different sources.

Keywords Combinatorial optimisation · Multi-objective optimisation · Cooperative methods · Metaheuristic · Routing · Scheduling

MSC classification (2000) 68T37 · 90B50 · 90C27 · 90C29

1 Introduction

Many real-world optimisation problems have to face a lot of difficulties, especially in the field of logistics. Indeed, they are often characterised by large and complex search spaces, multiple conflicting objective functions, and a host of uncertainties that

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have to be taken into account. Metaheuristics are natural candidates to solve those problems and make them preferable to classical optimisation methods. However, the development of efficient metaheuristics results in a complex process. The core subject of this work lies in the design, implementation and experimental analysis of metaheuristics for multiobjective optimisation, together with their applications to logistic problems from routing and scheduling. Firstly, a unified view of such approaches is presented, with a particular interest on evolutionary and local search algorithms. Next, some cooperative approaches, combining multiple metaheuristics for multiobjective optimisation are proposed. At last, the issue of uncertainty handling is discussed in the context of multiobjective optimisation.

As an example to illustrate the importance of multiobjective optimisation under uncertainty, scheduling problems are usually tackled in a single-objective and deterministic way. However, they are generally clearly multiobjective (T'Kindt and Billaut 2005), with criteria like makespan, flow-time, idle-time, tardiness, etc. Moreover, there data are subject to many uncertainties with respect to processing times or due dates (Billaut et al. 2008). This research area has received an increasing interest in recent years because of its difficulty, but yet practical matter.

2 Metaheuristics for multiobjective optimisation

One of the most challenging problem in multiobjective optimisation is related to the identification of the Pareto optimal set, or an approximation of it for difficult problems (Ehrgott 2005). First, we mainly concentrate on the development of metaheuristics dedicated to the approximation of this set. A unified view is presented for the design of effective metaheuristics dedicated to multiobjective optimisation problems of continuous and combinatorial nature. A particular emphasis is given to multiobjective-specific search components, including fitness assignment, diversity preservation and elitism. Innovative algorithmic contributions are then proposed: a simple elitist evolutionary algorithm and several local search approaches. All these concepts have been integrated into an open-source software framework dedicated to the flexible and reusable implementation of metaheuristics for multiobjective optimisation, namely ParadisEO-MOEO [1] (Liefooghe et al. 2009).

In terms of application and experimental analysis, a number of search methods are applied to solve realistic multiobjective combinatorial optimisation problems. Hence, the Ring Star problem aims at finding a cycle in a subset of nodes of a graph while optimising two types of costs: a ring cost, related to the cycle length, and an assignment cost from non-visited nodes to visited ones (Liefooghe et al. 2010). For the first time, this problem has been explicitly formulated in a multiobjective way. In addition, we also experimentally analysed and validated our approaches on a two- and three-objective permutation flow-shop scheduling problem.

[1] The ParadisEO-MOEO software framework is available for download at the following URL: http://paradiseo.gforge.inria.fr

3 Hybrid and parallel metaheuristics for multiobjective optimisation

In a second time, we focus on the development of cooperative metaheuristics, both sequential and parallel, still in the context of multiobjective optimisation. Indeed, metaheuristics are now considered as reference methods for many difficult optimisation problems. However, it has become clear that focusing on a single type of metaheuristic is rather restrictive. In many cases, an appropriate combination of concepts coming from different methodologies can produce more effective and more flexible algorithms when large-size problems from real world are to be solved. Hybrid metaheuristics consist of combining different metaheuristics, or incorporating techniques from artificial intelligence and operational research into a metaheuristic.

In this context, we propose two general-purpose cooperative models, and experimentally validate their interests over the multiobjective combinatorial optimisation problems under study. A first approach is based on the iterative and cyclic execution of evolutionary and local search phases (Liefooghe et al. 2010). The search process adaptively set a proper balance between exploration and exploitation with respect to the convergence of the main algorithm. Secondly, we propose a parallel model based on the decomposition of the objective space by means of multiple reference points (Figueira et al. 2010). The approximation of subparts of the Pareto optimal set can then be performed independently for each reference point, so that the computation can be performed on a parallel and distributed environment.

4 Metaheuristics for multiobjective optimisation in uncertain environments

At last, we observe that most real-world optimisation problems are subject to uncertainties, either on the objective functions, on the environmental parameters or on the decision variables (Jin and Branke 2005).

These different sources of uncertainty must be taken into account during the modelling and the resolution of the problem. From a multiobjective standpoint, these uncertainties constitute a major obstacle since they prevent the identification of the Pareto optimal set. Despite their flexibility, metaheuristics are rarely explored to address problems of stochastic nature. However, they seem to be interesting candidates. We show that, with minimal adjustments, they can be applied to a wide variety of optimisation problems under uncertainty, including multiobjective problems. We first study how to model these different sources of uncertainty into the problem formulation, based on a sampling approach. A classification of existing methodologies is proposed and is divided into three classes of strategies based on (1) a deterministic resolution, (2) the addition of extra constraints or objectives, and (3) the modification of methodologies through probabilistic dominance relations or uncertainty-handling fitness assignment schemes.

Then, algorithmic adaptations of existing metaheuristics are proposed to solve such problems, and possible alternatives are identified in terms of search methods and performance assessment. Finally, a flow-shop scheduling problem is for the first time formulated while taking both its multiobjective and stochastic aspects into account simultaneously. This problem is then taken as a benchmark for analysing our approaches experimentally (Liefooghe et al. 2007).

5 Conclusion and perspectives

To summarise, multiple contributions have been proposed for solving multiobjective optimisation problems with metaheuristics, including new stand-alone, hybrid, parallel and uncertainty-handling approaches, together with various applications in the field of logistics. In the future, we plan to apply our methodologies to real-world problems from green logistics, where environmental issues naturally lead to the consideration of additional criteria, and can then be formulated as multiobjective optimisation problems.

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